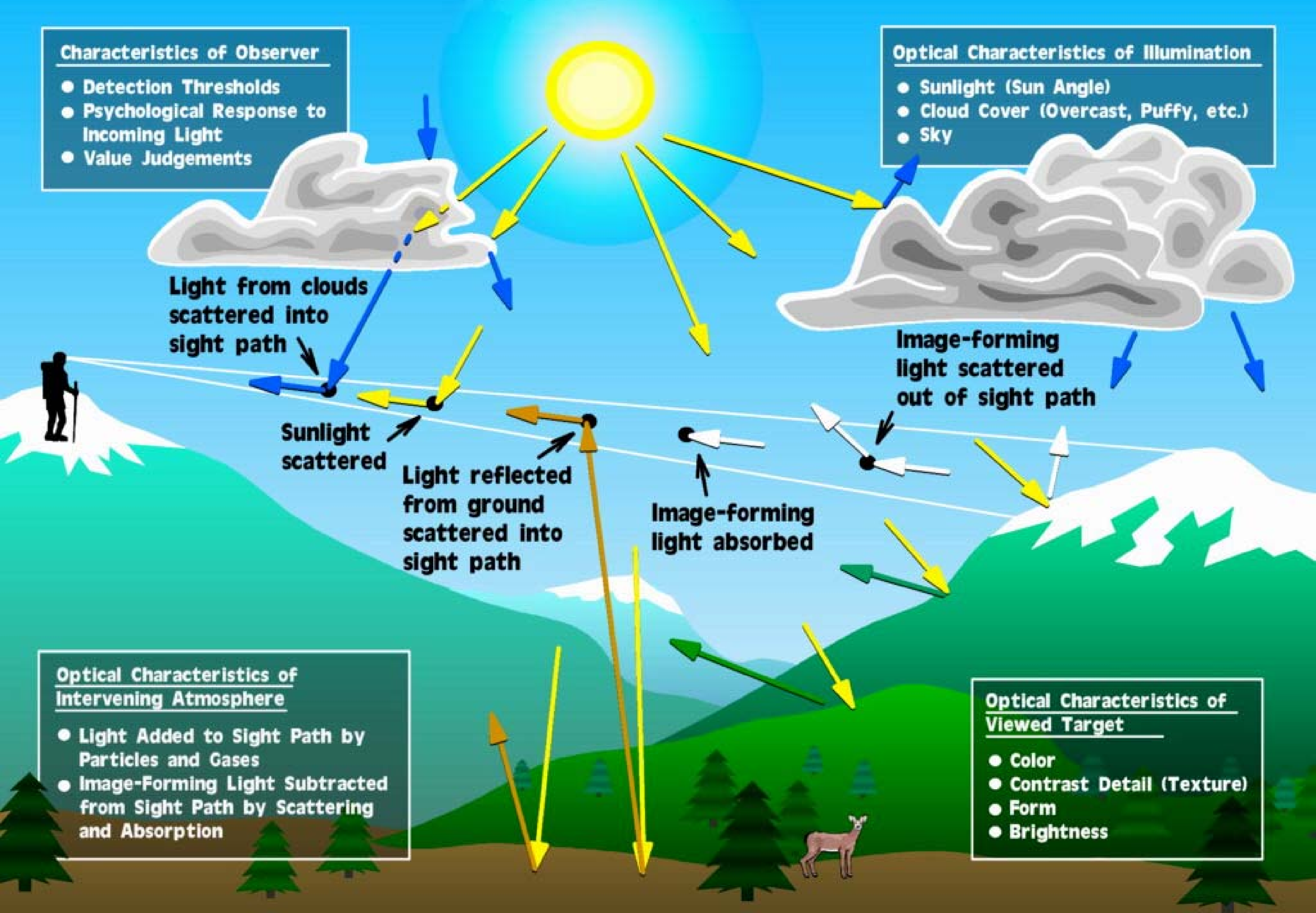
How Does Air Pollution Impair Visibility?

- Particles and gases scatter and absorb light, which reduces contrast
  - Scattering is random reflections of light – It both reduces image forming light and generates non-image forming light
  - Absorption is the conversion of light to heat – It reduces image forming light
  - Visibility of distant objects is poorer than nearby objects because light must pass by a greater number of particles and gas molecules

The Seeing of a Landscape Feature



Optical Effects of Particles & Gases

Types of Particles

- Ammonium Sulfate
- Ammonium Nitrate
- Organic Carbon Particulates
- Elemental Carbon Particulates
- Other Fine Material (< 2.5 micron)
- Coarse Material (> 2.5 micron)

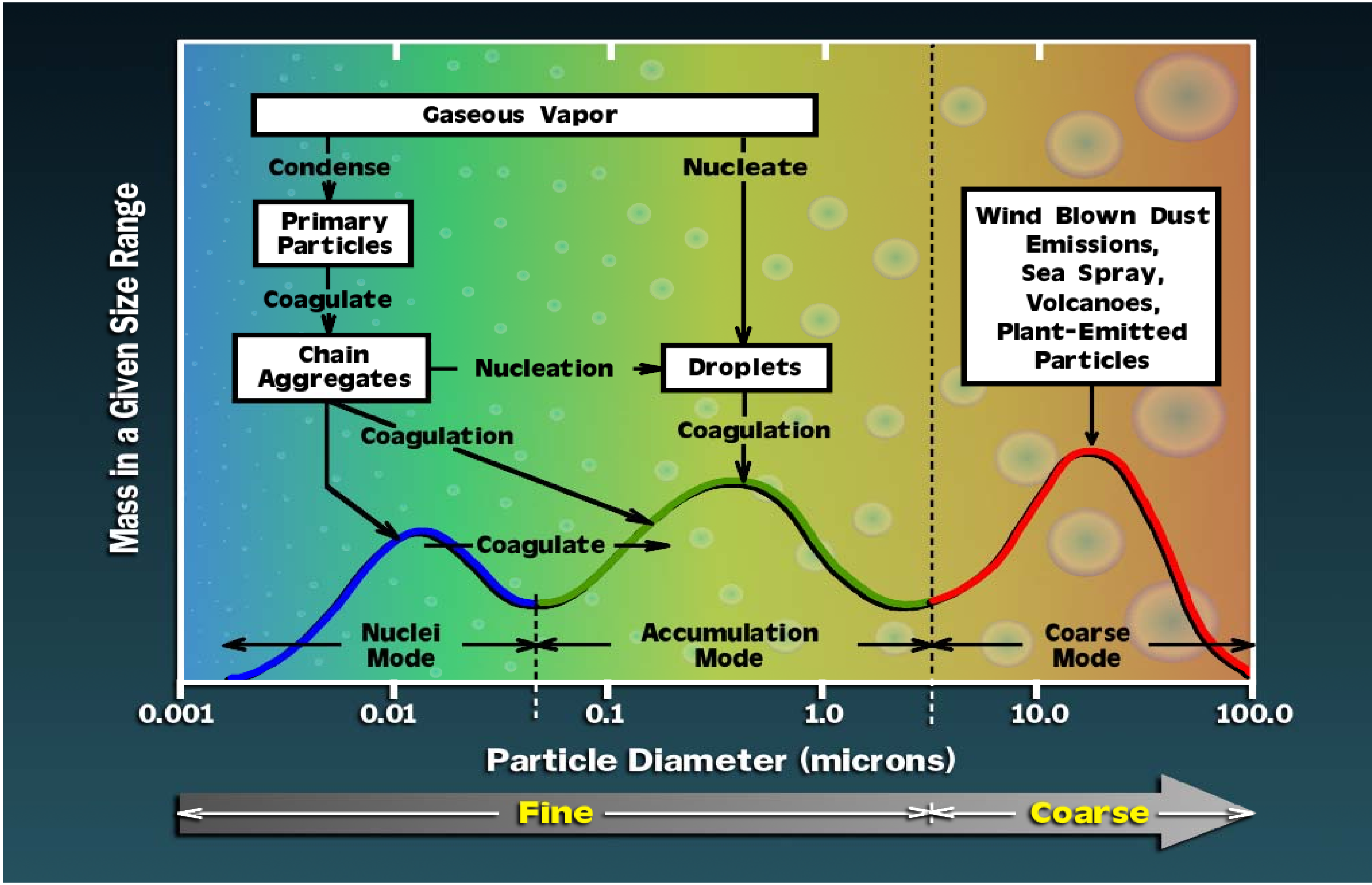
Sources of Particles

- Sulfur Dioxide Gas to Sulfates
- Oxides of Nitrogen to Nitrates
- Organic Gases to Organic Particulate
- Direct emission of Organic Particulate
- Direct emission of Elemental Carbon
- Direct emission of Fine Materials
- Direct emission of Coarse Material

Sources of Emissions

- Natural Sources
  - Wild Fire
  - Volcanic Activity
  - Biogenic and Geogenic processes
- Man-made Sources
  - Industrial sources (utilities, smelters, etc)
  - Mobile sources (cars, trucks, trains, etc)
  - Area sources (smoke, dust, other gases)

Particle Size Distribution



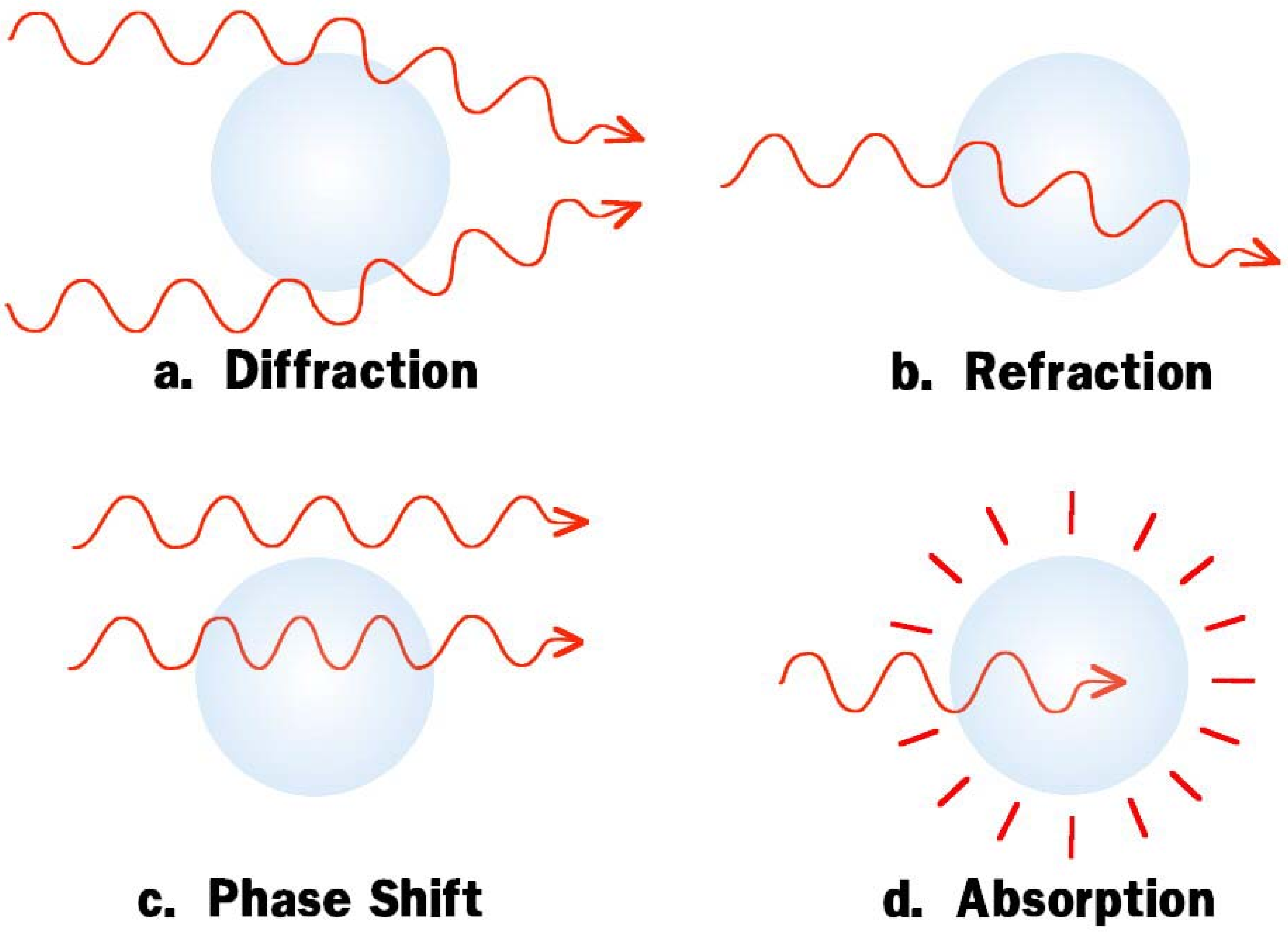
Light Extinction Coefficient

- The fractional attenuation of light per unit distance is known as the light extinction coefficient.
  - Light extinction coefficient is often represented by the symbol b_{ext}
  - Light extinction coefficient units are one over length, for example inverse kilometer (km^{-1}) or inverse megameters (Mm^{-1} *1000= km^{-1}).

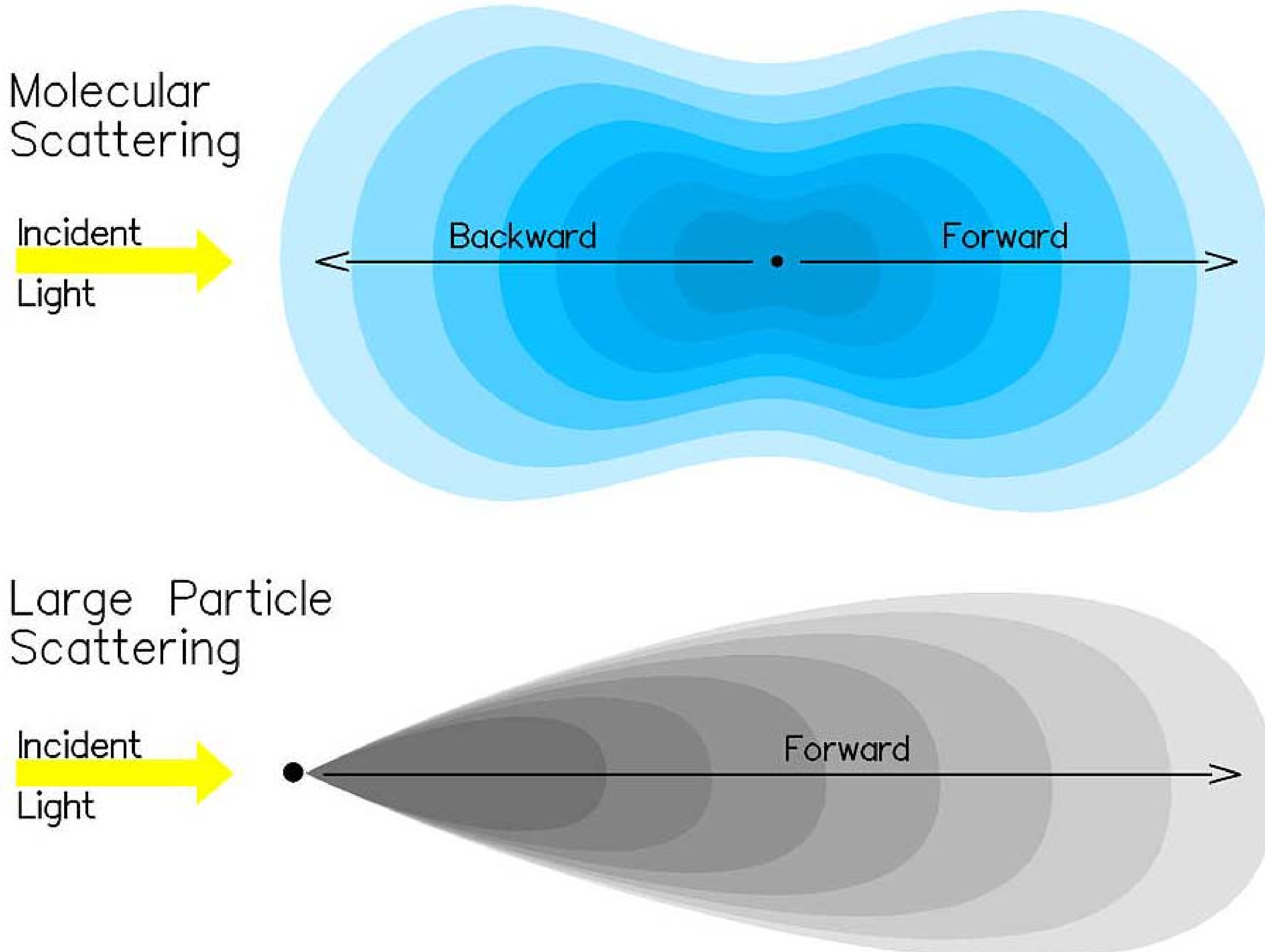
Light Extinction Coefficient

- Made up of Four Parts:
  - Scattering by gases
  - Absorption by gases
  - Scattering by particles
  - Absorption by particles

Components of Scattering and Extinction



Forward and Backward Scattering



Light Scattering by Gases, b_{sg}

- Nitrogen, oxygen and all other gas molecules in the air scatter light – This is also known as Rayleigh scattering
  - It depends only on the density of the atmosphere so is most dependent on elevation above sea level
  - It ranges from about 9 to 11 Mm^{-1} at the earths surface, so 10 Mm^{-1} is often used as a standard value
  - A Rayleigh or particle-free atmosphere is as-good-as it gets with respect to visibility
  - Gases scatter Blue light (small λ ~0.45 μm) about 4.4 times more effectively than Red light (large λ ~0.65 μm). Why is the sky blue?

Light Absorption by Gases, b_{ag}

- Nitrogen dioxide, NO_2 is the only commonly occurring gas in the atmosphere that absorbs in the visible spectrum.
  - Amount of absorption depend only on concentration
  - NO_2 absorbs in the blue spectrum so it gives a yellow or brown appearance if enough is present
  - Except for plumes of sources with good particle controls, NO_2 absorption is usually ignored because it is small compared to the associated particle scattering (e.g. in a polluted urban environment)

Light Scattering by Particles, b_{sp}

- All particles scatter light – Light scattering usually dominates the light extinction coefficient
  - Particle scattering can be directly monitored using nephelometers
  - The amount of particle scattering depends principally on the particles size, but also on its shape, and composition
  - Average scattering efficiencies that are typically used vary from less than $1 m^2/g$ (crustal species) to $4 m^2/g$ (organic species) depending primarily on particle size distributions for the different species

Light Absorption by Particles, b_{ap}

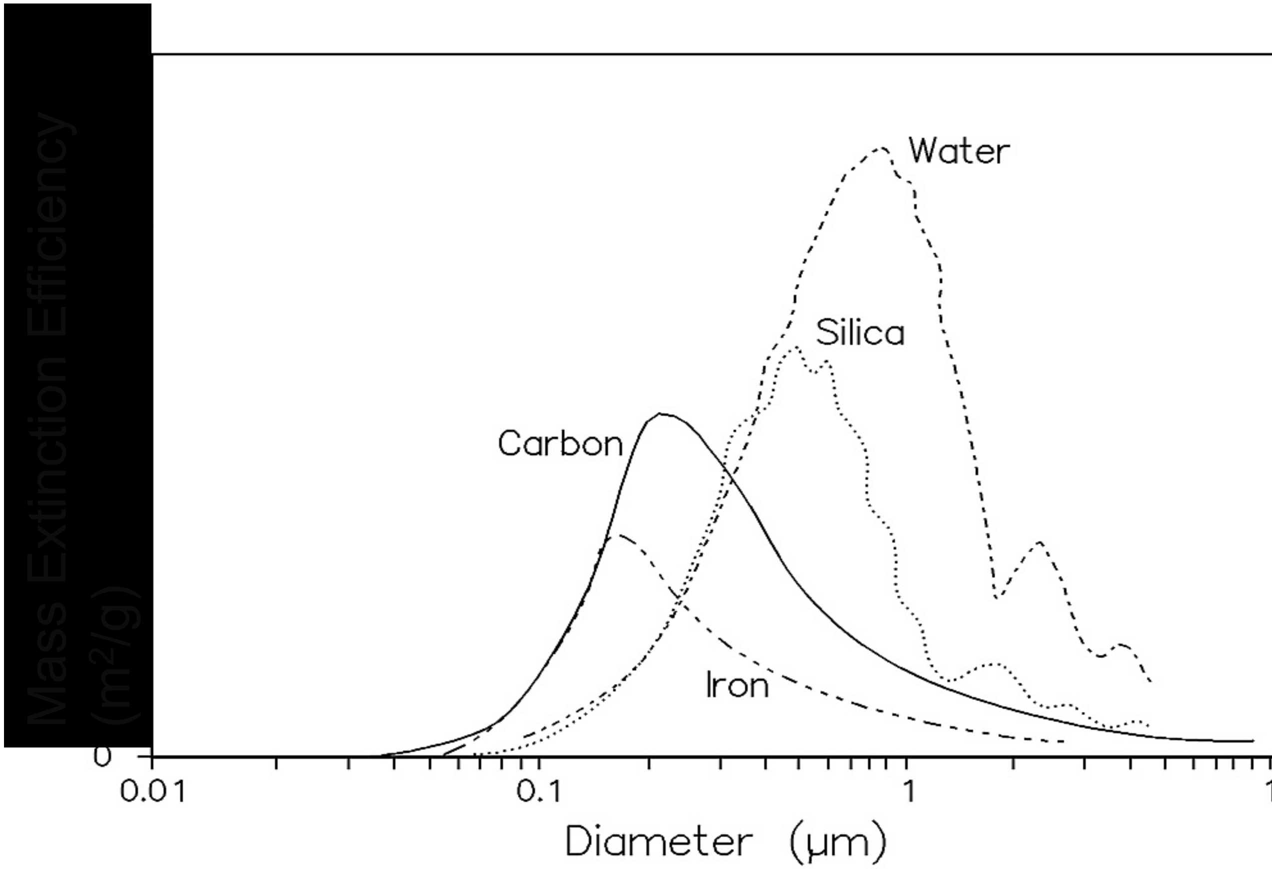
- Principally caused by elemental carbon, also referred to as soot or light absorbing carbon, but is also caused by some crustal minerals
  - Particle absorption can be monitored by measuring light transmission through filter samples
  - Amount of light absorbed by a particle depends on its size, shape, and composition
  - An average extinction efficiency (extinction coefficient divided by the mass concentration) of $10 m^2/g$ is used for elemental carbon

Mass Light Scattering Efficiency

- For many particles (a concentration) we can define a mass extinction efficiency α
- This is the sum total of the scattering cross sectional areas per unit mass

$$[\alpha] = m^2/g$$

Particle Mass Extinction Efficiency for Different Species



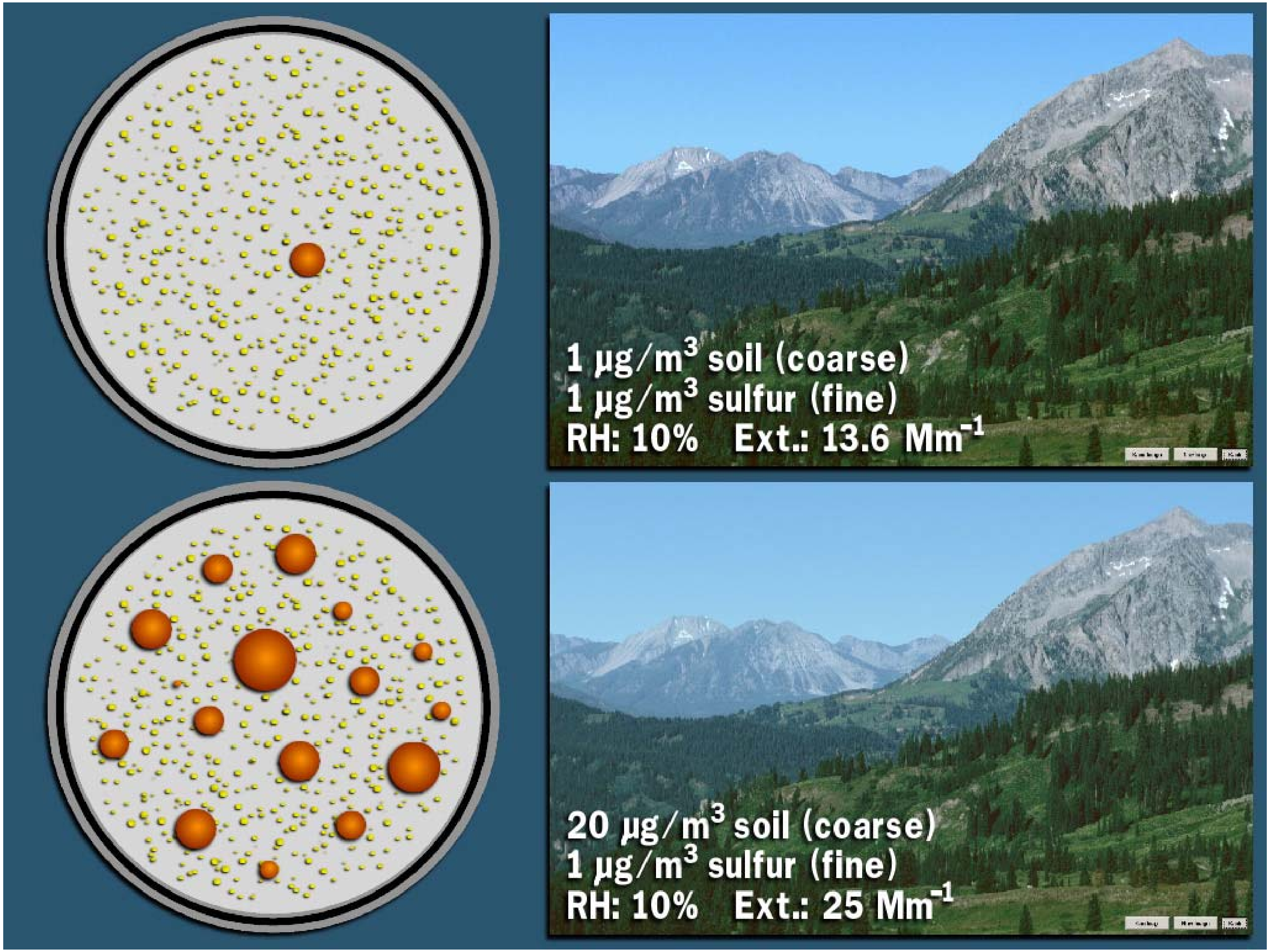
•Extinction efficiency depends on particle size, index of refraction and density

•Carbon and Iron also absorb light

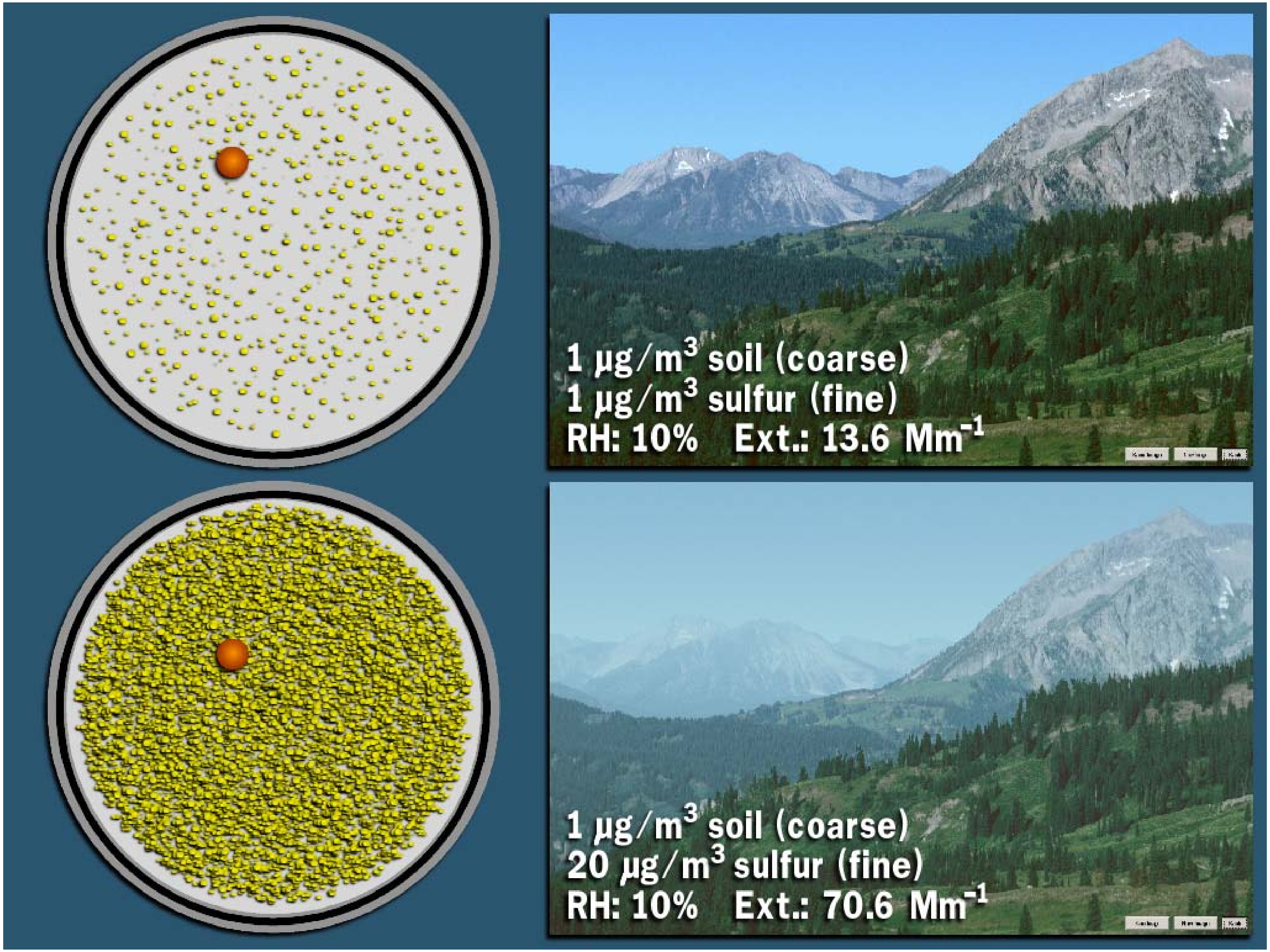
Aerosol Light Extinction Calculation

- Algorithm used by the Regional Haze Rule

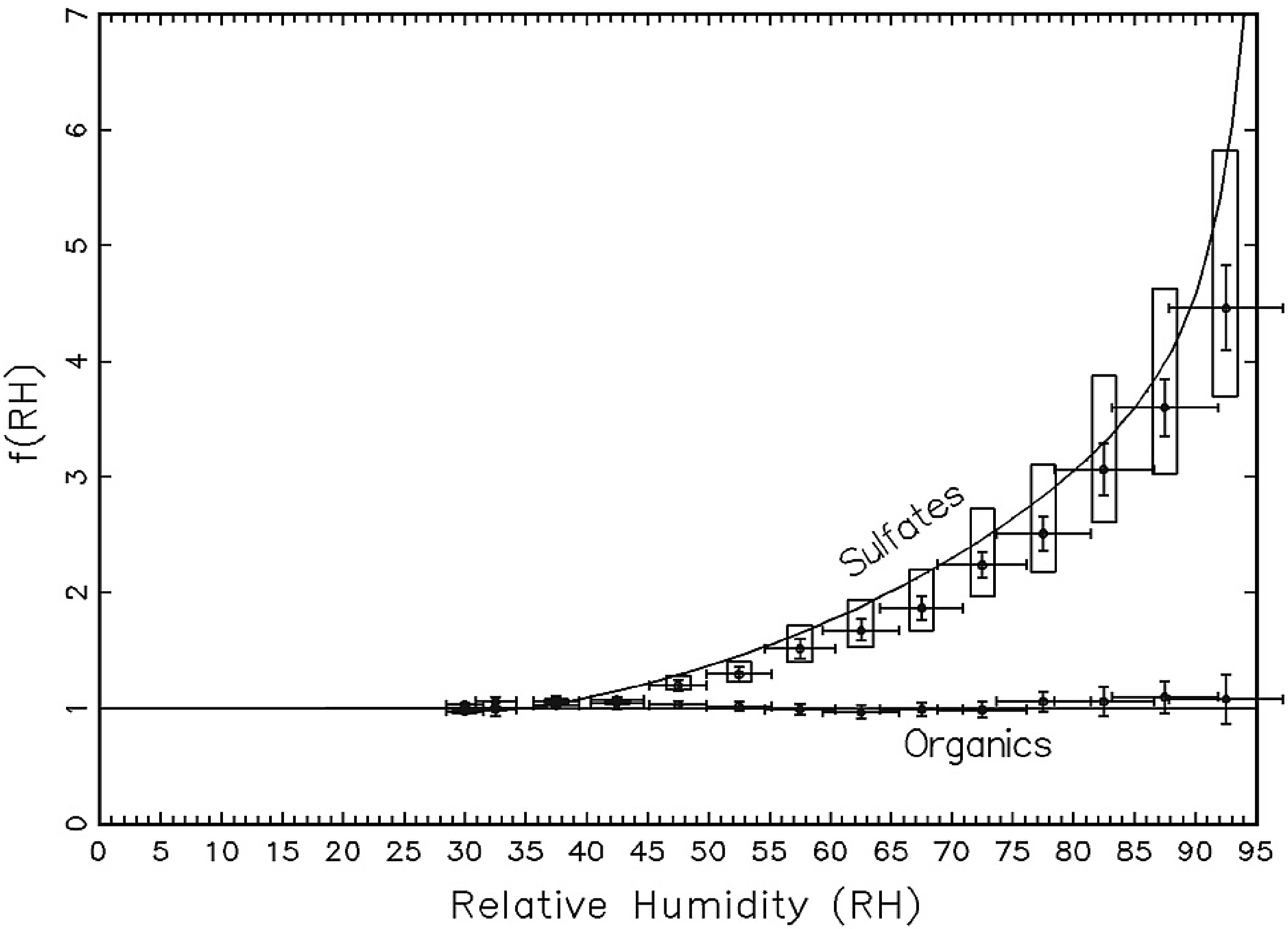
Effect of increasing coarse mass by a factor of 20



Effect of increasing fine sulfate by a factor of 20



Estimated f(rh) for Sulfate and Organics



Effects of high humidity for high coarse mass & high sulfate days